

Graphene and the improvement of concrete properties

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Abstract

A documentary review was carried out on the production and publication of research papers related to the study of the variable called graphene and the improvement of concrete properties. The purpose of the bibliometric analysis proposed in this document is to know the main characteristics of the volume of publications registered in Scopus database during the period 2015-2020 in Latin American countries, achieving the identification of 523 publications. The information provided by said platform was organized by means of tables and figures categorizing the information by Year of Publication, Country of Origin, Area of Knowledge and Type of Publication. Once these characteristics were described, the position of different authors regarding the proposed topic was referenced by means of a qualitative analysis. Among the main findings of this research, it is found that Brazil, with 303 publications, is the Latin American country with the highest production. The area of knowledge that made the greatest contribution to the construction of bibliographic material related to the study of graphene and the improvement of the properties of concrete was engineering with 284 published documents, and the type of publication that was most used during the period mentioned above was the journal article, which represents 71% of the total scientific production.

Keywords: Graphene, concrete, improvements

1. Introduction

Concrete is one of the main materials used in construction, so it is one of the most consumed products in the development of infrastructure, and this material is even more used than wood and steel thanks to its resistance to water and its initial consistency which allows molding it according to the need that arises. So, over the years new substances have been implemented to improve the quality of this product and optimize its mechanical properties.

With the application of several admixtures, the behavior of concrete has been improved. One of the most talked about admixtures today is graphene, which is an industrial material composed of carbon, which makes it very resistant and very easy to transfer its properties when mixed with other products, which makes it an innovative element in the new technological era thanks to its characteristics that help to improve energy efficiency in constructions.

Contreras and Aliaga (Incorporation of graphene to improve the compressive mechanical behavior of concrete $F'c = 210 \text{ kg/cm}^2$, Lima 2019, 2019). states that graphene can improve the durability, permeability, workability and resistance of concrete. There is no doubt that those who know this material mention that graphene is stronger than steel, thus increasing the resistance with very thin sheets of some elements such as concrete. This addition of graphene to concrete translates into an improvement in the consistency of the concrete allowing its fluidity and easy moldability and at the time of drying a more resistant consistency that helps to include nanotechnology in construction and architecture and to improve its mechanical behavior to compression.

Coppa (2017), in his analysis of the use of graphene in the improvement of concrete found that with graphene the cost of concrete increases by 47% but also translates into a greater benefit by obtaining greater strength. This shows the benefits of implementing nanotechnology in concrete in order to improve buildings and make these processes more in line with the new technological era. Therefore, it is important to know in terms of bibliographic resources, the current state of research on graphene and improvements in the properties of concrete in Latin America, so a bibliometric analysis of the scientific production registered in Scopus database during the period 2016-2021 is proposed to answer the question: How has been the production and publication of research papers related to the study of the variable graphene and the improvement of concrete properties in Latin America during the period 2016-2021?

2. General Objective

To analyze from a bibliometric and bibliographic perspective, the production of high impact research papers on the variable Graphene and the improvement of concrete properties in Latin America during the period 2016-2021.

3. Methodology

Quantitative analysis of the information provided by Scopus is performed under a bibliometric approach on the scientific production related to graphene and the improvement of concrete properties. Also, from a qualitative perspective, examples of some research works published in the area of study mentioned above are analyzed from a bibliographic approach to describe the position of different authors on the proposed topic.

The search is performed through the tool provided by Scopus and the parameters referenced in Table 1 are established.

3.1 Methodological design

	PHASE	DESCRIPTION	CLASSIFICATION
PHASE 1	DATA COLLECTION	Data was collected using the Scopus web page search tool, through which a total of 523 publications were identified.	Published papers whose study variables are related to Graphene and the improvement of concrete properties Research papers published during the period 2015-2020. Limited to Latin American countries. Without distinction of area of knowledge. Without distinction of type of publication.
PHASE 2	CONSTRUCTION OF ANALYSIS MATERIAL	The information identified in the previous phase is organized. The classification will be made by means of graphs, figures and tables based on data provided by Scopus.	Word Co-occurrence. Year of publication Country of origin of the publication. Area of knowledge. Type of publication
PHASE 3	DRAFTING OF CONCLUSIONS AND FINAL DOCUMENT	After the analysis carried out in the previous phase, we proceed to the drafting of the conclusions and the preparation of the final document.	

Table 1. Methodological design.

Source: Own elaboration (2022)

4. Results

4.1 Co-occurrence of words

Figure 1 shows the co-occurrence of keywords within the publications identified in the Scopus database.

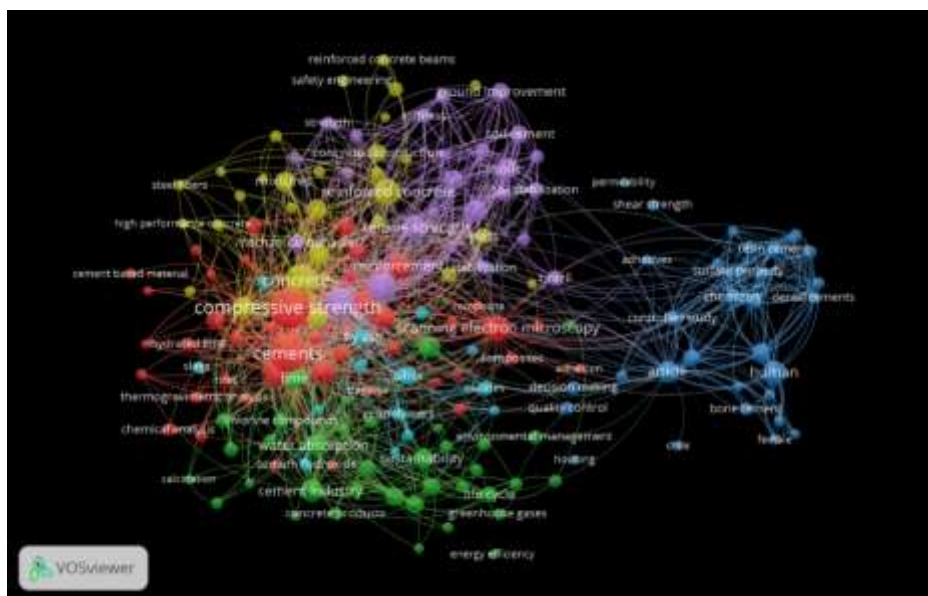


Figure 1. Co-occurrence of words

Source: Own elaboration (2022); based on data provided by Scopus.

As shown in Figure 1, the most used keywords are cement and compressive strength, which refer to the most talked-about improvements, since the aim is to study the admixtures that allow a better mechanical behavior of the concrete when compression is performed and thus improve its workability when the concrete is fresh and its strength when the concrete has already hardened. There are also keywords such as texture, porosity, silicates, quality control, and concrete base materials, which represent some factors that should be taken into account in the implementation of improvements in the materials that make up the cement in order to determine the changes that this material would undergo in its texture and the pros and cons that this entails. The environmental factor includes key words such as sustainability, greenhouse gases, environmental management, energy efficiency and water absorption, where the risks and benefits that these innovations may represent for the environment or for the correct use of resources are considered. Therefore, concrete improvements should evaluate whether they contribute to making this product more sustainable and environmentally friendly or if, on the contrary, these new materials cause damage to the ecosystem, either with greater emission of greenhouse gases or excessive use of renewable and non-renewable natural resources.

4.2 Distribution of scientific production by year of publication.

Figure 2 shows how the scientific production is distributed according to the year of publication, taking into account that the period from 2015 to 2020 is taken.

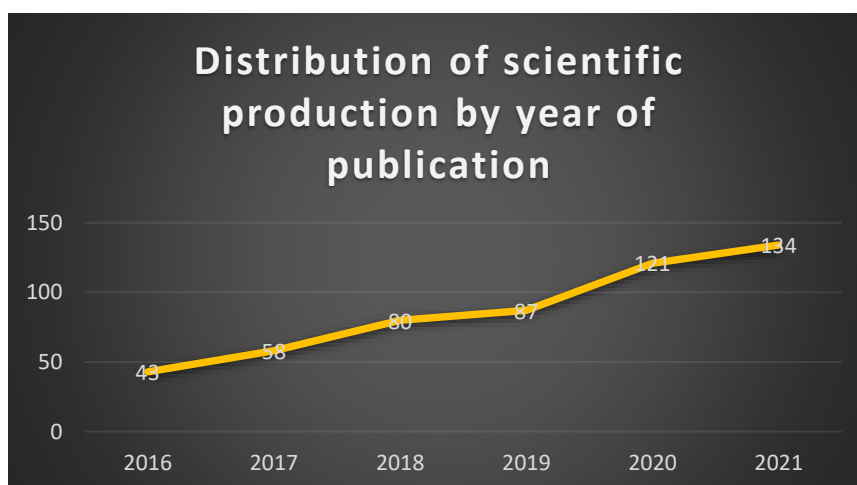


Figure 2. Distribution of scientific production by year of publication.

Source: Own elaboration (2022); based on data provided by Scopus.

2021 is the year with the highest number of publications registered in Scopus, with a total of 134 publications, among which is the title “*Evaluation of the physical and mechanical properties of concrete modified with recycled glass crushed by means of a proportion adjustment with the ACI 211.1 method*” (Castro-Cardona, et al., 2021). In this article, it is stated that although the Colombian concrete industry in recent years has presented a lot of changes, which translates into accelerated growth, the way in which the raw material is obtained represents a challenge for environmental management. Therefore, this article presents as a proposal to curb these harmful effects to the environment the modification of a concrete mixture whose manufacture replaces the fine aggregate (Fa) by recycled glass crushed (RCG) using a particle size <1.18 mm, obtained from window manufacturing waste. This concludes that there is a significant improvement in mechanical strength as the recycled crushed glass content increases, and an intensification of pozzolanic reactivity at early ages.

In second place is 2020, with 121 papers related to the variables under study, among which is the title “*Mechanical and microstructural investigation of multiscale cementitious composites developed from sisal fibers and microcrystalline cellulose*” (Filho, Parveen, Rana, & Vanderlei, 2020). This article presents an alternative of cementitious composites, in this experiment sisal fibers and microcrystalline cellulose (MCC) are used in combination to develop multiscale cementitious composites with improved strength, modulus and fracture energy. The results indicated the formation of a higher amount of hydration products in multiscale composites due to the positive effect of MCC on cement hydration, resulting in a denser microstructure with a lower pore size and an improved fiber-matrix interface for improved strength.

In third place is 2019, with 87 papers registered in Scopus related to Graphene and improvements in concrete properties. Within these papers is the paper entitled “*Analysis of the compressive strength property of concrete modified with sugarcane bagasse fibers (Saccharum Officinarum)*” (Huertas, Martinez, & Espitia, 2019). This document presents an alternative to make the concrete industry more sustainable, showing the use of natural fibers as aggregate in the concrete mix as it is an environmentally friendly material since it uses agricultural residues such as sugar cane bagasse fiber. This study was carried out by means of compression tests and scanning electron microscopy, which showed the percentages of addition of these fibers to improve the mechanical behavior of the concrete.

4.3 Distribution of scientific production by country of origin.

Figure 3 shows the distribution of scientific production according to the nationality of the authors.

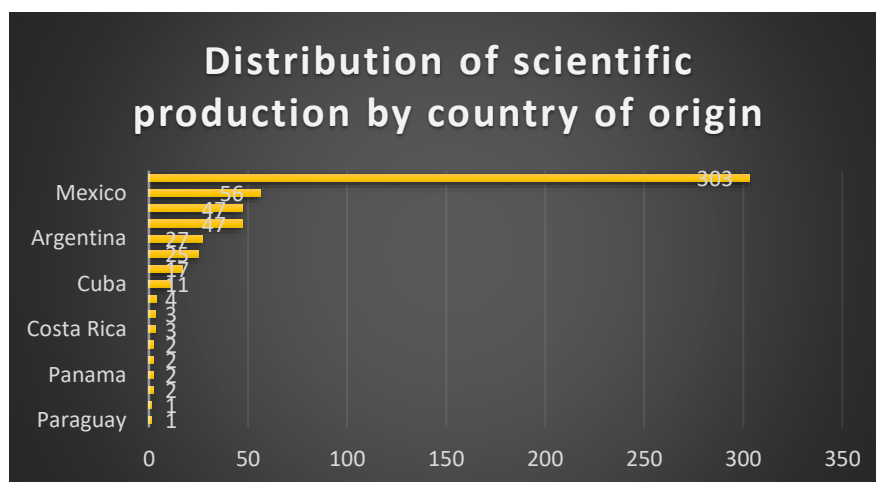


Figure 3. Distribution of scientific production by country of origin.

Source: Own elaboration (2022); based on data provided by Scopus.

Brazil is the Latin American country with the highest number of bibliographic records published in high impact journals indexed in Scopus database during the period 2016-2021, achieving a total of 303 documents among which is “*Asphalt concrete mixtures modified with polymeric residues by wet and dry processes: A review of the literature*” (Habert, et al., 2020). This article states that the production of cement and concrete generates a substantial emission of greenhouse gases and puts at risk the availability of natural resources, such as water, so it is necessary to implement new strategies to limit its environmental impact. This review seeks to shed light on the available solutions that can be implemented in the next decade and beyond to reduce greenhouse gas emissions from cement and concrete production by focusing on minor improvements that can be achieved along the value chain, such as the use of complementary cementitious materials and the optimization of the clinker content of cement. It concludes that the use of these materials can have a significant impact on reducing greenhouse gas emissions by up to 50% if all stakeholders are involved as they balance social needs, environmental requirements and technical feasibility.

In second place is Mexico with 56 registered documents, among which is the article entitled “*Mechanical optimization of concrete with recycled pet fibers from a statistical-experimental study*”. (Meza, Pujadas, López-Carreño, Meza, & Pardo-Bosch, 2021). This article shows that recycled fiber is an opportunity to reduce the levels of waste in the world and increase the mechanical performance of concrete, taking into account that it helps ductility and post-cracking resistance. So, this study is conducted through statistical experimental analysis to evaluate recycled PET fiber reinforced concrete with various fiber dosage and aspect ratio, having as a result that fiber dosage has more influence on responses than its fiber aspect ratio, with statistical relationship on tensile toughness,

equivalent flexural strength ratio, volumetric weight and number of fibers. This generates superior performance to control samples, with a similar improvement to those reinforced with virgin fibers, which helps to conserve and reuse resources.

At this point, it is worth noting that the production of scientific publications, when classified by country of origin, presents a special characteristic and that is the collaboration between authors with different affiliations to both public and private institutions, and these institutions can be from the same country or from different nationalities, so that the production of an article co-authored by different authors from different countries of origin allows each of the countries to add up as a unit in the overall publications. This is best explained in Figure 4, which shows the flow of collaborative work from different countries.

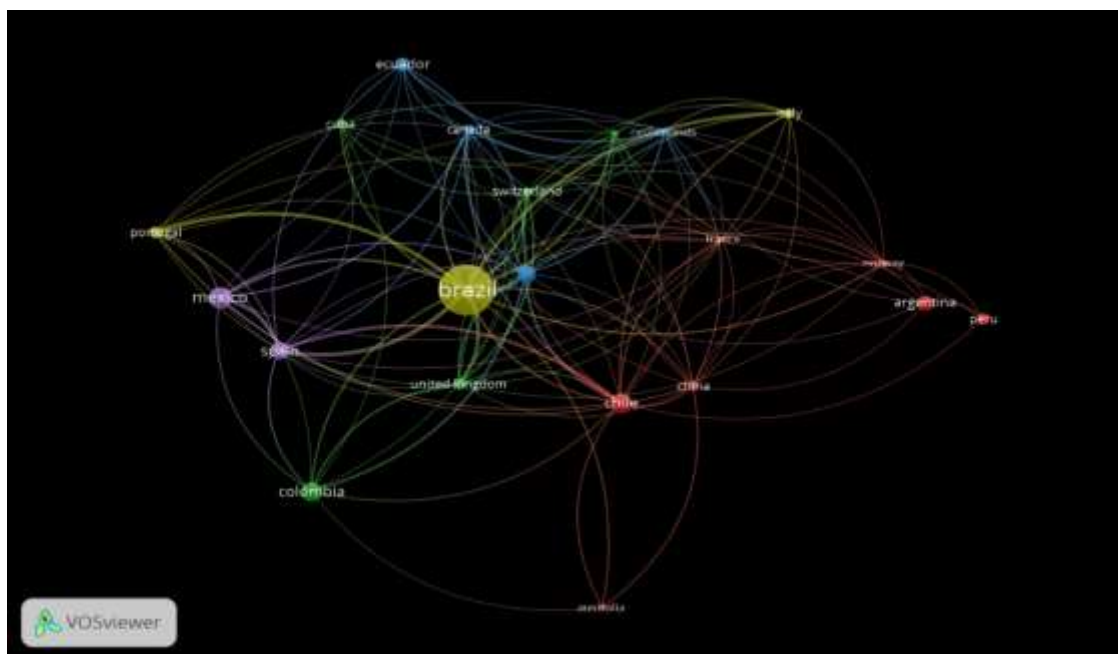


Figure 4. Co-citations between countries.

Source: Own elaboration (2022); based on data provided by Scopus.

Figure 4 shows Brazil as the country with the highest participation in research related to improvements in the properties of concrete and graphene in collaboration with authors affiliated to institutions mainly from Switzerland, the United Kingdom and Canada, which shows that not only research works were presented with authors of Latin American origin. Such as the case of Chile that presents publications with countries like Australia, Spain and Noruega, in these publications is the one with the title “*Durability of self-compacting concrete with addition of masonry residues when exposed to carbonation and chloride media*” (Silva & Delvasto, 2021). This research analyzes the durability of self-compacting concrete (SCC) with masonry waste (MW) taken from construction and demolition waste (CDW) as a partial replacement of Ordinary Portland Cement (OPC) through an experimental study in which 3 different styles of concrete were used and evaluated through a compressive strength test, water absorption, porosity, sorption, accelerated and natural carbonation, and rapid chloride penetration test.

4.4 Distribution of scientific production by area of knowledge

Figure 5 shows how the production of scientific publications is distributed according to the area of knowledge through which the different research methodologies are executed.

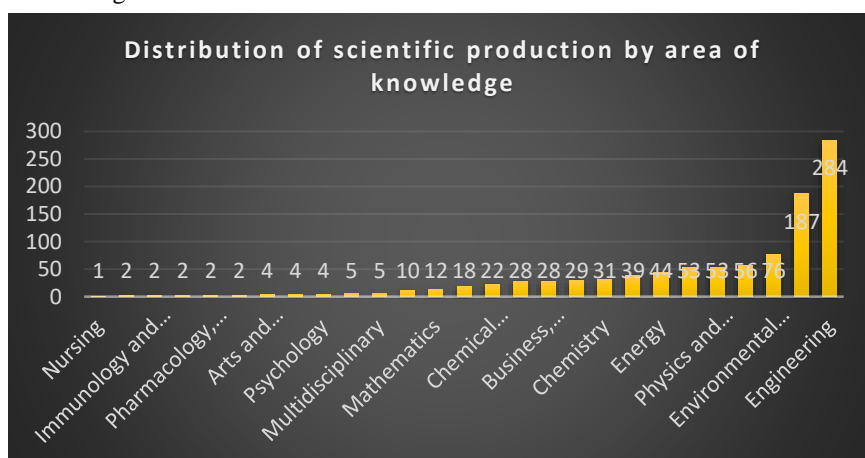


Figure 5. Distribution of scientific production by area of knowledge.

Source: Own elaboration (2022); based on data provided by Scopus.

Engineering is the area of knowledge with the largest number of contribution through the theories that are framed in it, in the search for new knowledge about Graphene and improvements in the properties of concrete having 284 papers within which is “*Long-term durability properties of geo polymer concrete: an in-depth review*” (Amran, et al., 2021). This article aims to provide an inclusive review on the production of supplementary cementitious materials (SCM), their economic performances, environmental and durability impacts, the conceptual model for geo polymerization, factors affecting durability and function and long-term durability analyzing mostly geo polymer concrete and geocrete. Concluding that more long-term durability studies are required to provide test methods and validation techniques.

In second place is scientific material having 187 publications related to the variables under study within which is the article entitled “*Improving the performance of asphalt mixtures with glass macrofibers*” (Morea & Zerbino, 2018). This article explores the use of glass microfibers in asphalt concrete mixtures because although many works show the reinforcement of asphalt mixtures with short fibers, there is a lack of information on the design and behavior of asphalt mixtures incorporating macro fibers. So, it was concluded that fibers have been used to reinforce materials and short and long fibers have wide use in Portland cement concrete to control cracking and provide residual capacity. There are improvements in fracture behavior at low and medium temperatures and macro fibers increased the first peak fracture toughness and gave higher residual tensile capacity.

4.5 Type of publication

Figure 6 shows how the bibliographic production is distributed according to the type of publication chosen by the authors.

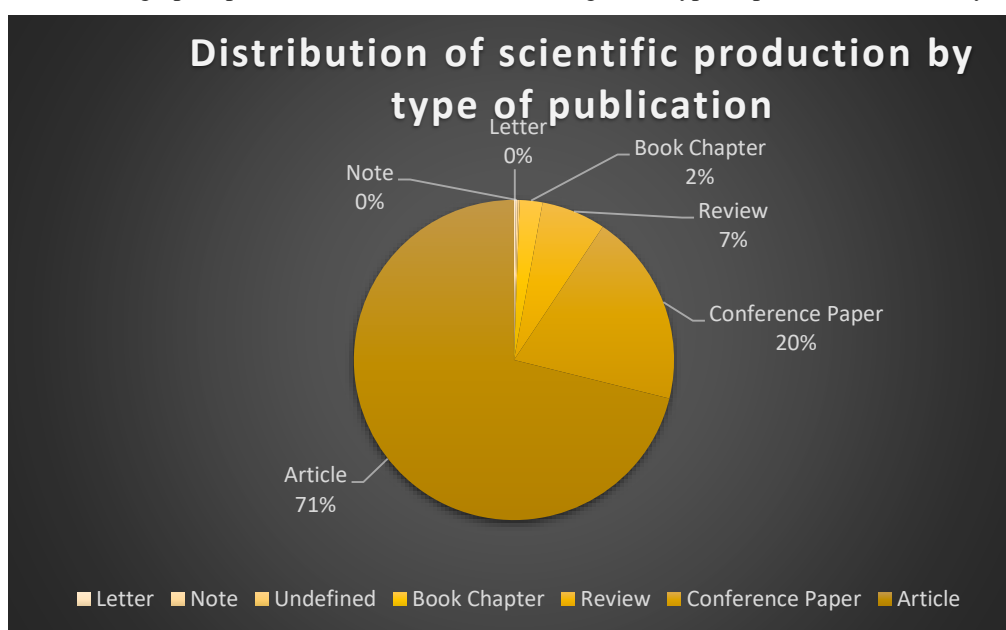


Figure 6. Type of publication

Source: Own elaboration (2022); based on data provided by Scopus.

As shown in Figure 6, within the different types of publications, 71% of the total number of documents identified through Phase 1 of the Methodological Design, correspond to Journal Articles, among which is the one entitled “*Non-conventional treatment of bamboo Ca(OH)₂ for the reinforcement of cement composites*” (Sanchez-Echeverri, Medina-Perilla, & Ganjian, 2020). This paper compares the structural and morphological changes in Guadua angustifolia Kunth (GAK) fiber prepared in three different ways (chips, without bark and shredded) when a non-conventional alkaline treatment is applied. They found that the flexural strength increased by about 40% and the toughness tripled which translates into mechanical improvement by Ca(OH)₂ treatment of G fibers.

In second place are the conference proceedings representing 20% of the total of the identified documents related to the variables under study, within these documents is “*Evaluation of the thermal efficiency of the prototype scale of a sustainable housing using concrete with PET fibers (CFP) and the Trombe system*” (Dueñas, Soto, & Carrera, 2021). This conference paper presents an experimental investigation of the improvement of the thermal efficiency achieved by a housing prototype when including polyethylene terephthalate (PET) as a component of the concrete mix in the structural elements, which helps both to improve the properties of the concrete and to innovate in construction and in the resolution of social problems. The results of the present study show that this combination has allowed to considerably improve the thermal efficiency properties of the prototype house, which is an indicator of its performance when applied to full-scale housing.

5. Conclusions

Thanks to the bibliometric analysis proposed in this research, it can be determined that Brazil is the Latin American country with the largest number of bibliographic records in Scopus database during the period between 2016 and 2021 with a total of 303 documents. The scientific production related to the study of Graphene and improvements to the properties of concrete has presented a significant growth during the above mentioned period, from 43 publications in 2015 to 134 units in 2020, i.e., it was possible to greatly increase the creation of bibliographic records in a period of 5 years, which indicates the importance that Graphene represents in the improvements of the properties of concrete and how these contribute to innovate the concrete industry and offer better quality in materials for building.

Graphene is an additive that helps to implement nanotechnology in concrete in order to bring the industry in line with the new technological era by implementing measures that help connectivity, graphene helps the concrete to have a better mechanical behavior and to present a better workability while it is fresh in order to mold it as needed and a high resistance when the concrete has already dried, since this material is considered even more resistant than steel.

On the other hand, these improvements in the properties of concrete should also be aimed at making it a more sustainable product, as it is one of the most used in society and will surely be even more so in the coming years, so it is important to ensure a product that has the least possible harmful effects, so new alternatives have emerged such as the use of sugar cane fibers, bamboo, recycled crushed glass or PET plastic in order to make the most of the products, reducing the use of natural resources and avoiding the generation of greenhouse gases. All of the above allows this article to conclude by highlighting the importance of knowing in depth what graphene is and its usefulness in its addition to concrete, in addition to implementing improvements that seek a balance between economic growth, a quality product and environmental protection from the industry. That is why it is important to highlight the need for studies such as the one presented in this document, which make a tour of those texts that address the above-mentioned topic, in order to give the reader a broad view of the current situation of the literature on graphene and the improvement of concrete properties.

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